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Analysis of stress-strain states of casting crane traverse

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Abstract. The purpose of this paper is to analyze actual stress-strain states of casting crane traverse taking into account weight of lifted load, thermal effects and additional inertial loads. The object of the study is a pattern of stress distribution inside the traverse elements. Methodology is proposed for modeling and analyzing stress-strain states of the casting crane traverse based on strength calculations considering allowable stresses and FEM. Calculation scheme and equivalent model were developed, and FEM calculation was performed in CAD/CAE system. Regularity of stress distribution in the traverse is obtained, and possible ways to further research are identified.

1 Introduction

Casting cranes are operated in severe conditions. Their elements are exposed to significant dynamic loads and high temperatures. Need to develop a methodology for strength calculations of traverse elements of casting cranes was justified earlier [1-5] that would allow to: consider their actual working conditions, increase accuracy of calculations, increase their reliability and safety of operation. It was shown [6] that actual values of inertial loads during crane moving may exceed values considering during its design. In addition, recommendations were developed on choice of values of deviation angles of hoisting ropes from vertical when performing calculations of casting cranes elements on static strength and fatigue.

FEM implemented in the CAD/CAE systems is widely used during strength calculations and optimization of elements of hoisting-and-transport machines [7-12] that allows to: increase accuracy of performed calculations, obtain picture / chart with stress-strain states of the whole assembly, repeatedly conduct research using developed model.

2 Formulation of task

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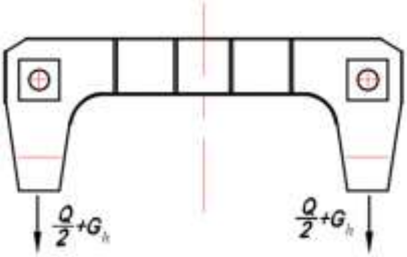
Facts of elements breakdowns of casting cranes traverses, metal frames of bridges and other equipment are known. Cranes are put out of operation for a long period of time to carry out repairs that only allows to revamp damages that have been occurred. It is also noted [6] that actual values of rope deflection angles during acceleration / deceleration may exceed values considered during design of cranes that also affects their reliability. Reliability improvement of casting cranes elements is possible, in particular, by refining methods and developing new methodologies for their design, determining and studying their stress-strain states using FEM and modern CAD/CAE systems.

Analysis of design calculations showed that more often in calculation scheme of casting crane traverse (refer to fig. 1,a) only action of vertical forces (refer to fig. 1,b) is considered.

It is believed that big factor of safety (for example, safety factor in vertical metal sheet is equal to 5.75 with acceptable one equal to 2.3) will ensure reliability and safety during operation. However, cases of breakdown of this element are known [1]. It is also known [13] that during some time (3-5 minutes) of pouring iron into converter temperature on outer surfaces of crane metal structures can reach 500-700°C.

Above mentioned points confirm the need to consider dynamic loads, horizontal force that occurs during acceleration / deceleration of crane and thermal loads on traverse.

a)



b)

Q is load capacity, G_h is hook weight

Fig. 1. Traverse of casting crane: a is general view; b is calculation scheme.

3 Objectives of this paper

Purpose of this paper are:

- simulation of loading during acceleration of casting crane and analysis of actual stress-strain states of its traverse taking into account thermal effects and additional inertial loads;
- development of recommendations for optimizing design of casting crane traverses.

Object of study is pattern of stress distribution in elements of traverse.

4 Materials and Methods

Traditional strength calculations of crane metal structures and their elements are based on assumption of flat scheme of their work, while their elements operate as spatial systems. For example, calculation of crane bridge with two span beams of sheet construction usually consists of calculation of individual beams with applied design loads. This approach is traditional due to the fact that calculation methods have evolved being based on manual method of calculation using simple counting devices. In complex cases it is difficult to estimate accuracy of such calculations without experimental verification on models and products [12].

At present, due to development of special software for calculating spatial structures a need to break down metal structures into flat elements gradually disappears. Practically all modern strength calculations are carried out using FEM. Therefore, to determine the actual stress-strain states of the traverse usage of calculation methodology with traditional engineering methods and FEM are proposed. As an example, a casting crane with lifting capacity of 450 tons is considered.

Calculation scheme with actual loads is proposed on fig. 2.

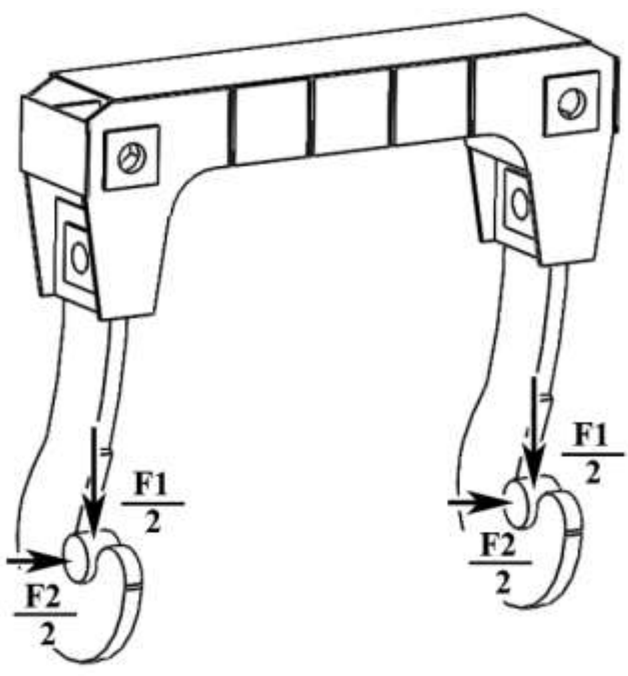


Fig. 2. Calculation scheme.

External forces acting on the traverse are applied to throat of the hook. These loads can be divided into three types:

1. Force $F1$ acting from weight of load and lifting hooks. It acts in a vertical plane:

$$F1 = (Q + 2 \cdot G_h) \cdot g = (450 + 2 \cdot 16) \cdot 9.81 \approx 4820kN. \tag{1}$$

2. Force $F2$ that acts during acceleration / deceleration. It acts in horizontal plane [2];

When crane moves with acceleration load is deflected at angle φ due to action of horizontal force [6]:

$$\mathrm{F2} = \mathrm{Q} \cdot \mathrm{tg\varphi}. \tag{2}$$

It is accepted that φ = 4°. For lifting capacity of 450 tons:

$$\mathrm{F2} = \mathrm{Q} \cdot \mathrm{tg}4^{\circ} = 450 \cdot 0.07 = 31.5\ \mathrm{ton} \approx 315\mathrm{kN}. \quad (3)$$

3. Thermal load *F*3 acting on the traverse is applied with assumption that outer (from the throat of hooks) surfaces of the traverse are uniformly heated to a temperature of 100°C. Some other considered options are:

- uniform heating of all elements of the traverse;
- presence of thermal protection of the traverse. It means that its selective surfaces are exposed to heat.

In addition, variant with effect of significant heat loads (400°C) was considered.

Developed model and accepted designations are shown on fig. 3.

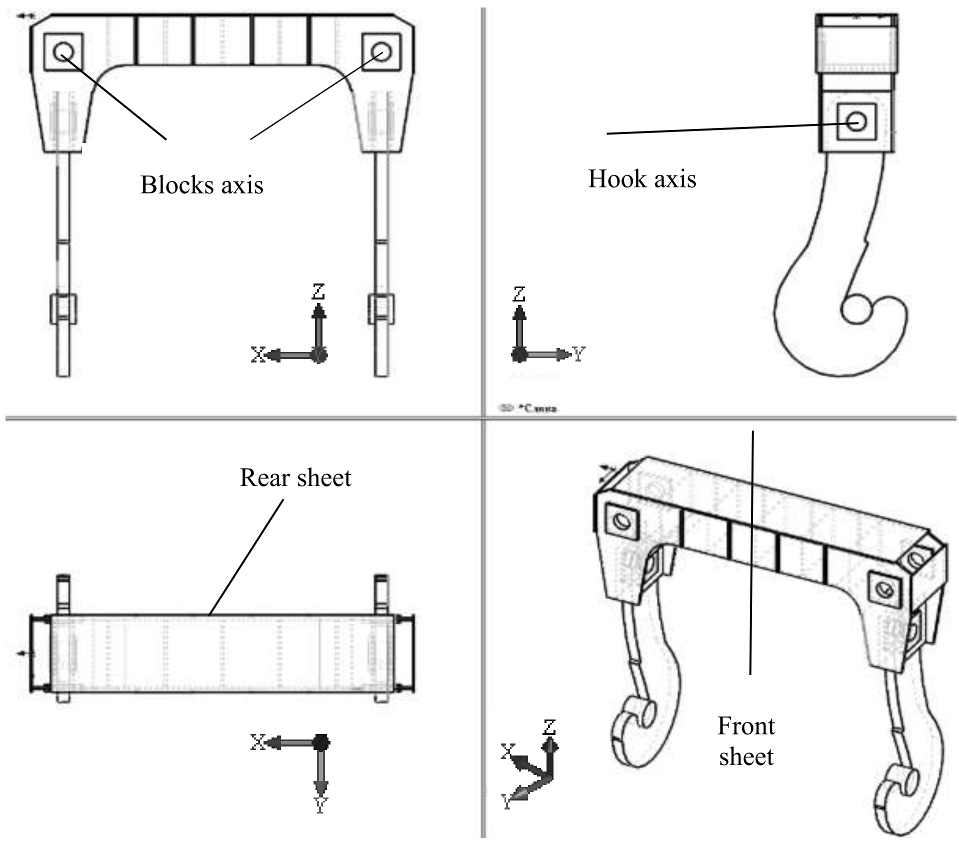


Fig. 3. General view of developed model and accepted designations.

In order to simulate behavior of a real object hooks were placed in the traverse. In the hooks throat axles of ladle were fixed. Forces *F*1 and *F*2 were applied to these axles (refer to fig. 4). Main geometric parameters are saved.

Attachment of the model was made as hinge at location of blocks axes (refer to fig. 4). Then by means of CAD/CAE software FEM mesh was generated (refer to fig. 5).

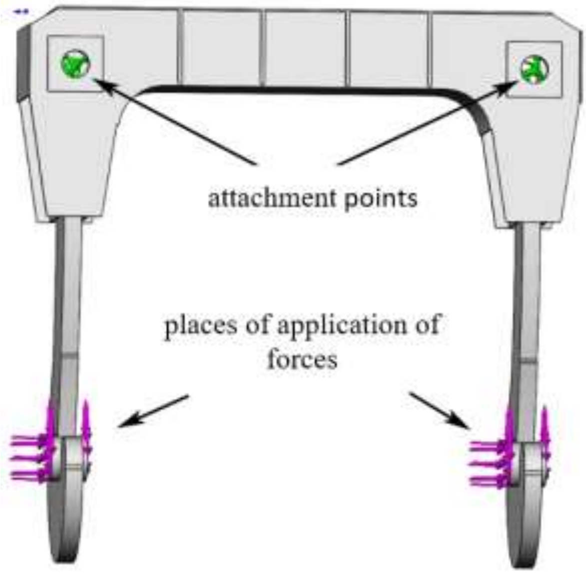


Fig. 4. Attachment points and places of application of forces of the model.

5 Results

As a result of modeling of the stress-strain state diagrams of equivalent stresses distribution in the model, diagrams of normal stresses distribution in three planes, diagram of safety factor distribution and diagram of equivalent stresses (von Mises) distribution using ISO restrictions for three variants of loads were obtained:

1. Action only of force *F1*;
2. Action only of forces *F1* and *F2*;
3. Action only of forces *F1* and *F2* taking into account heat load F3 acting on the outer surfaces of the traverse.

Diagrams of equivalent stresses distribution are shown in table 1. Comparing diagrams of equivalent stresses distribution (color change from blue to red) taking into consideration three load cases it is clear that the third variant is with bigger stress (refer to table 1) then the second and the first are followed.

Significant heat loads act quite a short time (3-5 minutes) compared with forces of the load weight and hooks. However, it is known [13] that there are no effective methods to protect casting crane elements from effects of hot gas emissions, flames, molten metal splashes from converter during pouring of liquid metal into it. Existing heat shields are not able to protect metal structures of the crane bridge from temperature effects. At the same time, metal frames elements are subjected to thermal effects, significant static and dynamic loads that lead to reduction of their service life.

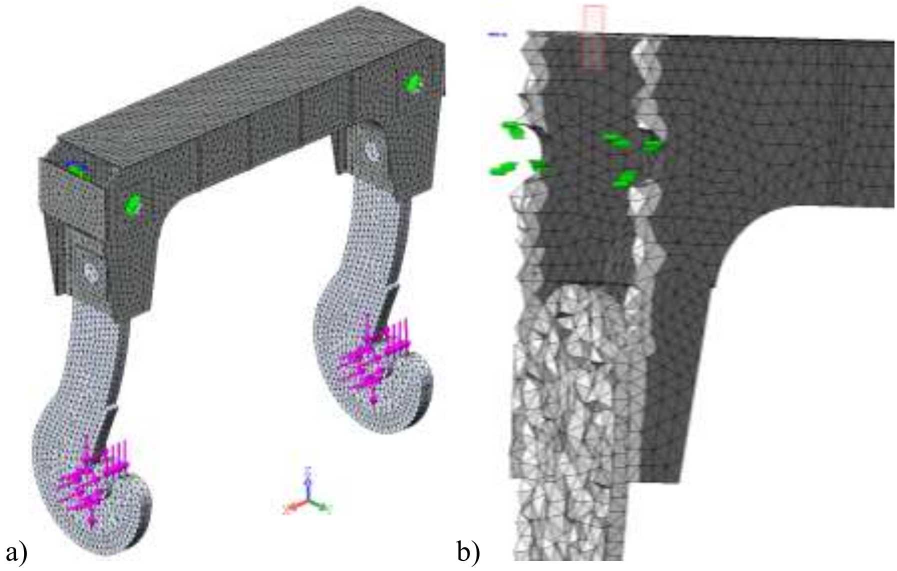
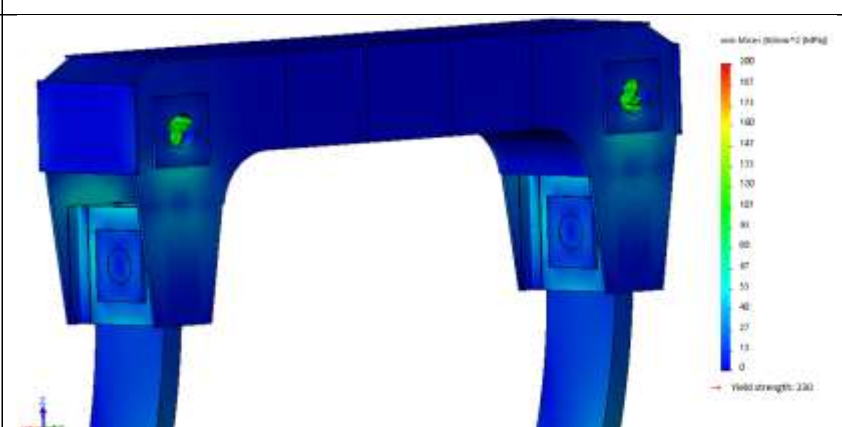


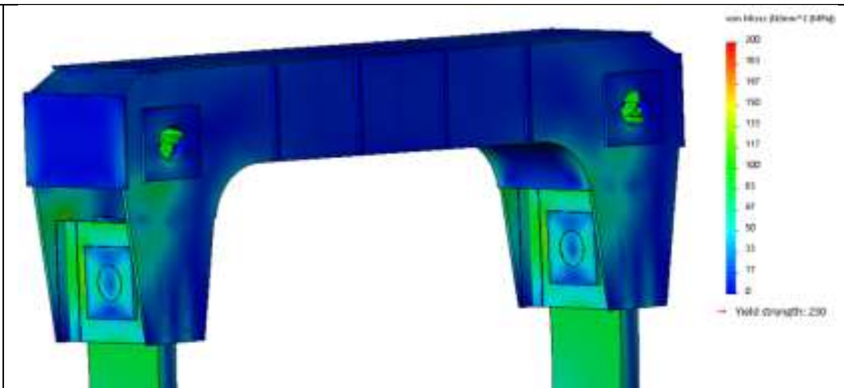
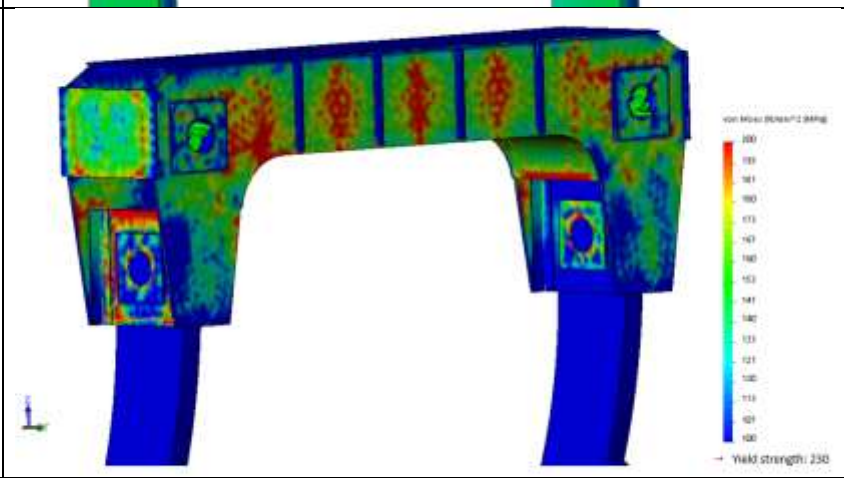
Fig 5. General view of mesh (a) and zoomed view of section (b).

It is proposed that thermal loads should be considered as a range of additional loads that are superimposed on the spectrum of main loads and take them into account in fatigue strength calculations. Their influence on the overall load, distribution in the elements of the traverse requires additional research and clarification which is beyond the scope of this work.

Considering above said it needs to analyze in detail the stress-strain state of the second variant of loading. Surface analysis of equivalent stress distribution in the model showed (refer to fig. 6) that the maximum values are concentrated at the attachment points of the hooks: front and rear sheets have about 85 MPa; sheets in which the axes of the hooks are fixed have about 125 MPa.

Table 1. Chart of equivalent stress distribution.

No. of loading variant	**Chart general view**
1st variant	

2nd variant	
3rd variant	

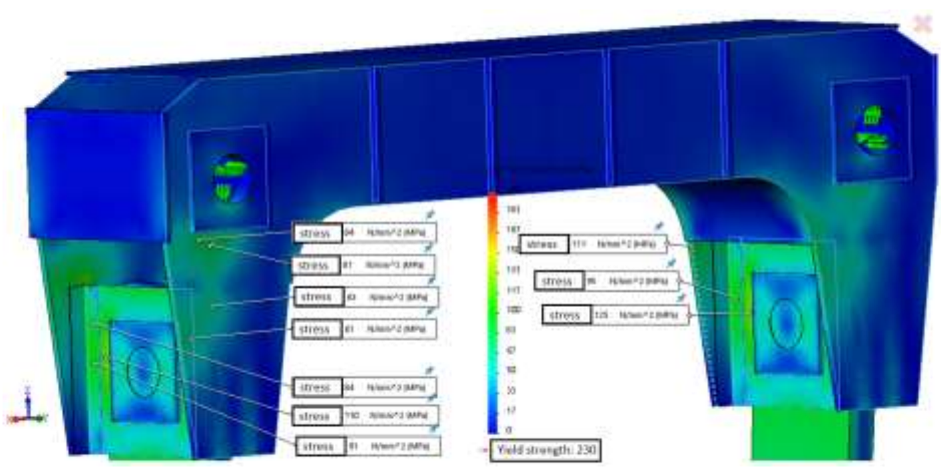


Fig 6. Equivalent stress values of the second variant of loading.

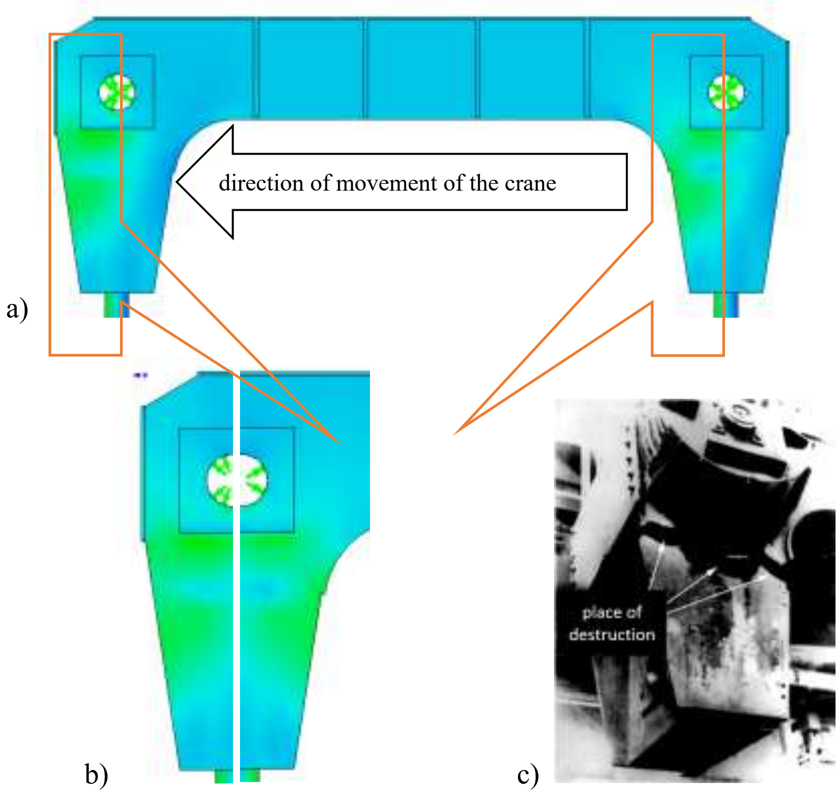


Fig 7. Chart of normal stress distribution (along the z axis) and photograph of the destroyed traverse: a) is general view of stress distribution; b) is combination of fragments of left and right walls (reflected relative to the vertical axis); c) is photograph of the broken traverse with shown place of breakdown / destruction.

Earlier in [1] case of side wall brake/crack of casting crane traverse was described. It is clear from fig. 7,a and b that chart of normal stresses distribution (along the z axis) and photograph of the destroyed traverse (refer to fig. 7,c) have correspondence of trajectory and location of the crack to concentration of maximum stresses in the side wall.

Loading of the traverse at full working cycle of the crane schedule consists of moving in two directions during transportation of loaded ladle and return to loading place. At this schedule each side of the traverse is loaded alternately and general view of actual loading corresponds to form shown on fig. 7,b.

Stresses in this element are not maximum with respect to others. It needs to analyze work and loaded state of the plates in which the hooks axes are fixed. In the outer plate of the left side (refer to fig. 6) stresses are about 110 MPa. Whereas in the inner plate on the same side (refer to fig. 8) the maximum stresses are around 35 MPa.

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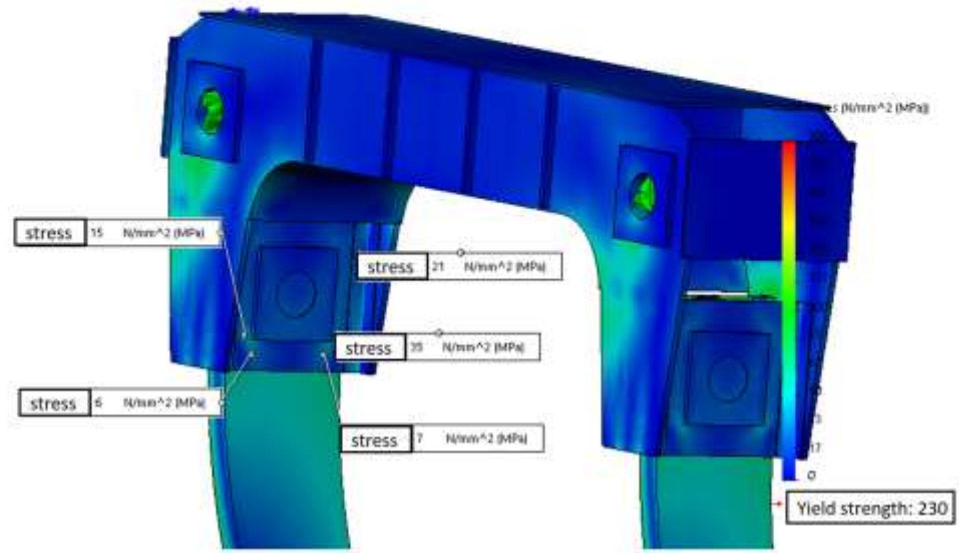
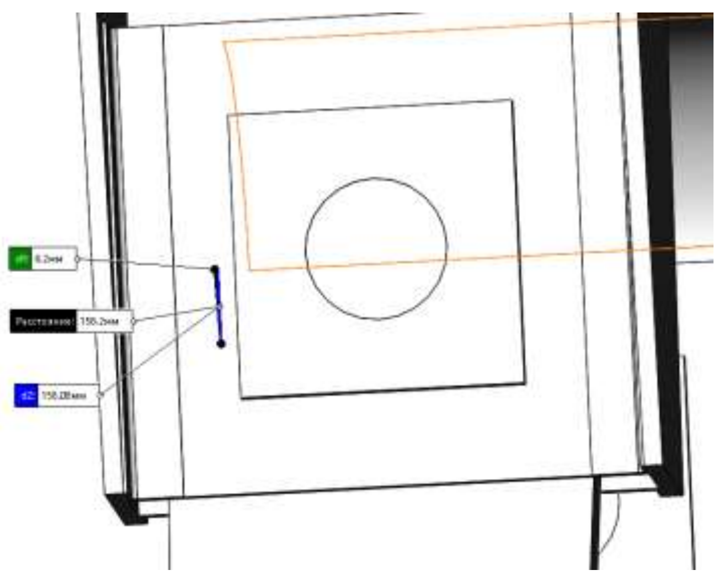
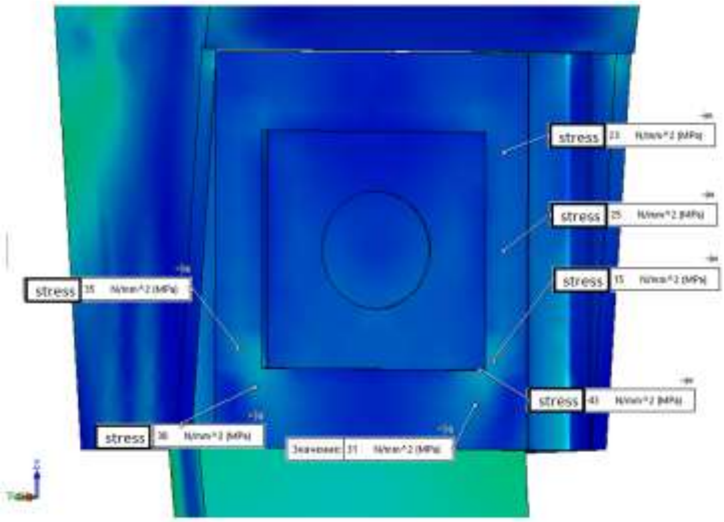


Fig 8. Values of equivalent stresses on the inner plate of the left side of the traverse according to the second variant of loading.

Such uneven distribution between two similar elements can be explained by imperfection of design which does not allow their uniform loading. As a result, the destruction occurred in the element with lower stress values and the same loading cycle. It can be modeled that the crack has appeared in the outer plate of the left side (refer to fig. 9,a) of the traverse. Its stress state is shown on fig. 9,b.



a)



b)

Fig 9. Traverse: a is area with simulated crack; b is values of equivalent stresses in the inner plate of the left side of the traverse according to the second variant of loading.

Analysis showed that stresses in the inner plate increased because it became more effective in work. In addition, stresses increased slightly in the front sheet which subsequently broken down. It can be assumed that breakdown in the side sheet did not occur due to principle (effect) known as survivability of structure when arise of defect / damage of one of elements does not fully affect performance of the whole structure. It is believed that further research in this direction using principles of optimal design [7] will make it possible to determine and propose optimal (in terms of uniform distribution of stresses in the elements) design of the traverse.

Selection of parameters and effective method for solving problems of metal frames optimization is important design stage. Many authors pay attention to resolve this task [14-17 and others]. It was noted [18] that significant number of works describe design of specific objects and contain information only about algorithms and their design results. Often design schemes of optimization objects are extremely simplified because they have small number of design variables. In this case model objects (beams, plates, shells) are most often considered rather than real structures with complexity of practical design models. In work [18] existing methods are considered in detail, examples are given and technology is proposed for solving problems of optimization of loaded multi-component structures and technological systems. Work [19] is devoted to consideration of the main methods of topological optimization which are used to increase specific strength of aerospace engineering assemblies by optimizing their geometrical parameters. It is noted that reducing mass and increasing specific strength of structures used in the aerospace industry are the most important tasks for designers around the world. Solution of these problems is directly connected with task of finding optimal geometric parameters of designed product [20]. Currently, topological optimization methods and corresponding software are used to solve this task. Usage of methods of optimal design allows finding the best design parameters that satisfy technological limitations and strength limitations, thus providing a minimum of the objective function [21, 22]. Today topological optimization methods are relatively new component of design procedure but are increasingly used, for example, in the aerospace industry.

Using topological optimization method and appropriate software it is possible to work with existing construction of the traverse. Design scheme, magnitude and direction of forces are preserved at the first approximation. Its result is shown on fig. 10.

Fig 10. Traverse after design study using topological optimization method.

General view of the traverse after its design study (refer to fig. 10) gives a visual representation of:

- effectiveness of metal use in the traverse elements;
- possibility of metal redistribution in order to optimize its design, e.g. by changing shape of the front and rear sheets, reduce their thickness (on fig. 10 these elements are completely absent in the middle part, although connection should be between left and right hooks).

It needs to change the scope of optimization and not be limited to existing elements to achieve more effect that is planned to be resolved soon.

6 Conclusions

1. Methods of designing metal frames (in particular, of casting cranes) that exist today require development and refinement since they do not allow to get a clear picture of stress-strain states of the whole frame.
2. Level of software and technical characteristics of modern computers can significantly simplify design process and improve accuracy of models for application of FEM.
3. Method with better accuracy is proposed that is used for strength calculation of the casting crane traverse that made it possible to obtain patterns of stress distribution in the traverse.
4. Performed analysis of stress-strain state of the traverse metal frame showed that values of equivalent stresses are unevenly distributed between elements and their values vary from 6MPa to 125MPa.
5. Thermal loads have significant effect on level of stresses. Additional research is required for evaluation of it.

6. There are still many questions concerning optimization of designs of casting cranes traverses metal frames that include: choosing basic construction parameters, justification of optimal shapes of elements and geometric characteristics of their sections in order to minimize mass and ensure uniform distribution of stresses.

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